**Testimony of Dr. Bogusz (Bo) Bienkiewicz**

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## Introduction

I very much appreciate the opportunity to appear before this committee and to testify in this hearing. In this testimony I will first present a brief overview of research activities carried out at the Wind Engineering and Fluids Laboratory at Colorado State University. Next, I will address issues associated with wind damage and damage mitigation in the United States, including a brief assessment of vulnerability to wind hazards and opportunities to reduce these vulnerabilities. Finally I will discuss a potential for strengthening the federal wind hazards research and development in the United States through establishment of the National Wind Hazards Reduction Program. These topics are discussed in more detail in a report entitled "Wind Engineering Research and Outreach Plan to Reduce Losses due to Wind Hazards"[1] prepared by American Association for Wind Engineering in collaboration with American Society of Civil Engineers. This report is enclosed with my testimony.

## Wind Engineering Research at Wind Engineering and Fluids Laboratory

For over 40 years, the Wind Engineering and Fluids Laboratory (WEFL), formerly the Fluid Dynamics and Diffusion Laboratory (www.windlab.colostate.edu) has been the center of excellence for fundamental and applied research in wind engineering and fluid dynamics. It is one of the international laboratories where the foundations of wind engineering were established. The core of WEFL are three large boundary-layer wind tunnels that allow for realistic modeling of the atmospheric boundary layer. This laboratory was originally established to perform fundamental research on the structure of turbulent boundary layer flows and to develop experimental techniques for modeling atmospheric boundary layers under various flow conditions and thermal stratifications. One of the early long-term research programs carried out at WEFL (in 1960-ties) was modeling and assessment of dispersion of chemical agents released from various sources, under varied atmospheric conditions. Post 9/11 concerns regarding potential intentional release of chemical/biological/radiological agent(s) in urban/suburban/rural settings, as addressed in a report recently released by the National Research Council[2], led to renewed interest by various federal/state and other public entities in the unique physical modeling capabilities existing at WEFL.

Over the years a great variety of studies of flows and their interaction with natural and built environment have been carried out at WEFL. A significant number of investigations addressed wind effects on buildings and structures and mitigation measures to minimize these effects. Wind engineering studies of a number of landmark buildings designed and subsequently built in the United States were carried out at WEFL. They included the New York's World Trade Center Towers, Chicago's Sears Tower and other tall buildings built in the United States. In addition, wind engineering studies were carried out to determine wind loading on and aerodynamic response of other structures (including long-span bridges and roofs, slender towers and stacks) and environmental assessments for sitting of fossil fuel and nuclear power plants as well as evaluation of sitting and performance of renewable energy (solar and wind power) installations. Determination and mitigation of wind effects on low-rise buildings and building components and systems (including innovative roofing systems) have been the main thrust of R&D carried out at WEFL in recent years.

A representative example of an involvement of WEFL in a coordinated effort focused on reducing vulnerability of built environment to wind hazards is participation of WEFL in a Cooperative Program in Wind Engineering (CPWE) involving researchers and students from Colorado State University (CSU) and Texas Tech University (TTU). This 10-year program supported by the National Science Foundation consisted of a number of research tasks that were addressed by collaborative teams comprising of researchers and students (graduate and undergraduate) from the two institutions. The CPWE teams made significant research, education and outreach contributions in the area of better understanding of wind hazards, their impact on low-rise buildings and structures, and mitigation of these hazards. It should be noted that one of the outcomes of the CPWE research is the design wind speed map incorporated in the ASCE 7 Standard[3]. Other major accomplishments of this program included: development of refined physical modeling techniques for wind engineering studies of low-rise buildings and structures, formulation of hybrid (incorporating analytical, numerical and experimental components) models for innovative (permeable, loose-laid) roofing systems, development of numerical simulation and visualization tools, and others. The outcomes of the CPWE effort have been subsequently utilized in applied research and in wind engineering service carried out at WEFL, TTU and at other institutions and private industry. A representative example of transfer of technology advanced through the CPWE at WEFL is application of the developed tools to predict and mitigate undesired wind effects on innovative roofing systems (including systems incorporating photovoltaic solar panels) and other roofing products developed by U.S. roofing manufacturers and solar energy providers. At TTU, various initiatives were undertaken to expand wind hazards research and enhance technology transfer through effective outreach activities.

## Impact of Windstorm Hazards in the United States

Wind-related events inflict major loss of life and material losses in the United States. According to a report published by RAND[4] (RAND Report), the annualized material losses attributed to wind hazards (inclusive of hurricanes, tornadoes and winter storms) are estimated to be $6.3 billion. They exceed by over 40% and 60% losses attributed respectively to earthquakes and floods. As the authors of the RAND report point out, attempts to provide the hazard loss data (and this applies to any natural hazard) face a number of challenges. They include the variability in occurrence times and magnitude of events resulting in measurable losses, the length of the averaging period used in calculating the annualized losses, and other factors. Calculation of the annualized losses is further complicated by lack of national database of the losses and changing society's vulnerability to wind and other hazards.

The above wind damage statistics are dominated by hurricane events of large magnitude. For example, in 1992 Hurricane Andrew resulted in $26.5 billion - the highest level of direct and indirect economic losses ever sustained in the United States as the result of a natural hazard event. Analysis of material damage due to landfall of hurricanes in the south-eastern United States over the period 1925 – 1995 showed that the overall damage due to the reported 244 hurricanes and significant tropical storms exceeded $340 billion, with most of the damage attributed to a relatively small number of strong hurricanes - of category 3 and higher on the Saffir-Simpson Scale[5].

The highest level of property damage and loss of life has been attributed in the United States to hurricanes, tropical storms, tornadoes and thunderstorms. While devastating effects of landfall of hurricanes have been primarily limited to the Atlantic and Gulf coast regions and the United States territories, hazards due to tornadoes and thunderstorms are of concern to inhabitants of most of the Nation. The highest numbers of fatalities and injuries are attributed to tornadoes. Although most of the largest tornadoes occur in the central United States - the tornado alley - tornadoes have been reported both west and east of the alley. Tornado touchdowns in Maryland, Utah and other states are good illustration of a wide territorial reach of destructive tornadoes. Thousands of thunderstorms occur every year all over the United States. Strong winds associated with passage of thunderstorms (at times accompanied by tornadoes, gust fronts and downbursts) result in a significant physical damage and human suffering. Local topographic features may lead to amplification of such winds, thus compounding adverse wind effects. Mountain ranges may lead to generation of local strong winds, such as down slope Chinook wind in Rocky Mountains, Santa Anna wind in California and strong winds in north - western U. S. and in Alaska.

Overall (approximate) measure of the potential wind hazard is represented by wind speed maps. Wind provisions of design codes and standards, such as the American Society of Civil Engineers Standard ASCE 7[3], provide the recommended design wind speed maps. They typically include disclaimers /restrictions to account for uncertainties/lack of reliable wind speed data.

Storm surge and heavy precipitation accompanying hurricanes both contribute to overall damage and have a potential for causing loss of life and various long-term undesired consequences. Precipitation associated with thunderstorms and tornadoes may lead to severe flash flooding. Other undesired effects associated with high-wind events include disruptions in transportation during winter storms (due to whiteouts and/or snowdrifts), summer dust storms and hail storms, and adverse wind effects on fires.

As a result of ongoing public and private efforts a number of wind hazards mitigation measures have been developed and put in practice in coastal and other regions of the United States. These measures have led to significant reduction in fatalities attributed to wind hazards, mainly due to improved warning times and life protection systems (shelters) in tornado prone regions, and improved forecasting of hurricane landfall and more effective evacuation measures in the Atlantic and Gulf coast areas of the United States.

While the available statistics on human losses due to wind hazards show an encouraging trend of reduction of loss of life, the data on the property losses due to wind hazards exhibit an opposite trend - increasing annualized losses - with alarmingly increasing rate of change in the losses, especially over the past decade. An intensified coordinated effort to reduce these losses is desirable.

**Barriers to Reducing Vulnerability to Wind Hazards**

In discussion of the material costs of natural disasters, the authors of the RAND Report noted a significant increase (reported by GAO, in 2002) in the disaster relief funds allocated by FEMA: from $7 billion over the period of 1978 – 89 to $39 billion over the next twelve-year period.

The authors identified a growing (indeed “exploding”) population in areas vulnerable to natural hazards (such as coastal areas) as one of primary reasons for such a dramatic increase in damage and the associated relief funds. A significant portion of these funds has been used to offset material losses due to wind hazards. It has been postulated that the above demographic trend will continue and that significant measures need to be urgently undertaken in order to address the issue of the increasing material losses (and associated relief funds) due to wind hazards.

A number of factors impeding mitigation of damage due to wind and other natural hazards have been identified by natural hazards mitigation community comprising of researchers and practitioners of broad background, decision and policy makers, and others. The domain of their evaluation included research and development, technology transfer and implementation, as well as outreach and education. Some of the impediments to effective mitigation of losses due to natural (including wind) hazards were postulated to be coupled with federal funding policies. The authors of the RAND Report concluded that in a number of programs explicit hazard loss reduction activities received the least R&D funding, while much of the spending supported short-term prediction capabilities of limited potential to long-term loss reduction that could improve the resilience of communities and infrastructure, and ultimately result in substantial reduction of losses. A large disparity between federal R&D funding allocated for different natural hazards also was noted.

As was reported before the Committee of Science of the U.S. House of Representatives (testimony by Dr. McCabe[6], during hearing on October 11, 2001), the average annual overall federal investment in research to mitigate impacts of wind hazards is estimated to be $ 5 - 10 million. It is instructive to compare this amount with FY2001 funding allocations for fundamental research by National Science Foundation: Civil & Mechanical Systems - Wind - $2.6 million, Earthquakes - $20.8 million; Atmospheric Sciences: Wind+Flood+Drought - $183.8 million, RAND Report, p. 23. It should be noted that the federal funding in excess of $100 million per annum has been invested over the past two decades to support activities geared towards reduction in earthquake losses, through the National Earthquake Hazards Reduction Program. A comparison of these funding levels with the quoted earlier estimate for the annualized wind hazards losses suggests that a significant increase in federal investment in activities geared towards reduction of losses due to wind hazards is urgently needed, justified, and has considerable potential for short- and long-term payoff.

**Wind Engineering/Wind Hazards Research Needs**

A list of wind engineering research areas identified as critical for reduction of wind-induced loses is provided in the report published by American Association for Wind Engineering[7]. It included: Collection of wind speed data using robust instrumentation and state-of-the art technology to map detailed structure of the wind, topographic effects, and long-term climate effects; Simulation of hurricanes and their wind fields and other extreme wind effects for statistical analysis of wind, wind loads, and wind-induced response of structures and their components; Modeling of wind-structure interaction, including effects of integral wind loads on structural systems, components and cladding, effectiveness of retrofitting schemes, effects of structural fatigue and impact by wind-generated missiles, design of cost effective tornado shelters and shelters for hurricane zones to minimize evacuation; Study of internal load paths, performance of structural systems, and effectiveness of connections between structural components; Field monitoring of structures in natural environment and large-scale tests in simulated loading environment; Research in debris impact potential in windstorm and development of impact resistant building components; Mapping of wind climate in urban areas; Health monitoring and structural control studies for mitigation of wind effects; Application of effective numerical schemes using computational fluid dynamics to determine the wind environment and wind loading on and response of buildings, structures, transportation systems and other critical components of civil engineering infrastructure, and to mitigate these effects; Development of effective techniques for collection and rapid archiving and dissemination of data acquired during post-disaster investigations; Development of cost-effective retrofit techniques to enhance wind resistance of existing structures; and Development and application of reliable techniques for cost-benefit analysis of wind hazards mitigation measures and other socio-economic evaluations.

**Opportunities to Reduce Vulnerability to Wind Hazards**

The existing R&D infrastructure and expertise in wind engineering and other disciplines pertinent to mitigation of wind hazards, recent advances in information technology as well as lessons learned from programs focused on mitigation of other natural hazards, especially earthquakes, form the basis that provides unique opportunities to enhance our efforts to reduce vulnerabilities to wind hazards.

The existing research infrastructure includes laboratory and field facilities used to investigate wind characteristics and wind effects on buildings and structures and their components. The main components of the laboratory infrastructure are long-test-section wind tunnels that allow for realistic modeling of boundary-layer winds and other flow modeling facilities that have been employed in exploratory modeling of other wind phenomena, including tornadoes, hurricanes and downburst outflows. Academic institutions in the United States involved in laboratory modeling of wind effects include: Colorado State University, Texas Tech University, Clemson University, Iowa State University, Louisiana State University and University of Notre Dame.

Over the years, extensive wind engineering field studies of wind effects on low-rise buildings and wind hazards mitigation have been carried out by researchers at Texas Tech University, at two sites in

Lubbock, TX. A field site to carry out wind engineering investigations primarily focused on manufactured homes was established (and jointly operated by the DOE's Idaho Environmental Engineering Laboratory and University of Wyoming) 30 miles west of Laramie, WY.

Several universities have established programs to collect high fidelity hurricane wind field information near ground, and wind loading on building envelope and building performance during strong wind events. A number of houses at various locations along Atlantic and Gulf coasts have been instrumented or outfitted with wiring and brackets for easy installation of instrumentation. These efforts have been carried out by researchers from Clemson University, University of Florida at Gainesville and University of Illinois at Urbana-Champagn. Several wind engineering research groups (Texas Tech University, Clemson University and University of Florida at Gainesville) use mobile towers (typically 30 feet in height) strategically positioned on an expected path of hurricanes or other high-wind events. These instrumented towers are equipped with back-up power supply and they are capable of withstanding wind speeds up to 200 mph. Recent upgrades of the towers included use of wireless phone communication (successfully deployed for the first time during landfall of Hurricane Isabel in 2003) to transmit the acquired data to a central database in near-real time.

Another example of an innovative application of the emerging sensors, data acquisition and transmission technology is a recent study coordinated by researchers from University of Notre Dame who have been supplementing traditional monitoring devices in measurement of wind-induced response of tall buildings using the Global Positioning System (GPS).

The above cases are only a representative sample of applications of new technologies incoroporated in current R&D focused on mitigation of wind hazards. The revolutionary role of information technology (IT) and unmatched opportunities resulting from its application in efforts geared to reduce vulnerability to natural disasters were discussed in RAND Report. Specific applications of IT in monitoring and simulating seismic hazards and structural response due to earthquakes, as well as in remote data acquisition and interpretation coupled with rapid communication and visualization to aid broad range of stakeholders (ranging from R&D through decision-making and emergency personnel) were discussed in EERI Report[8] . The described applications (of IT) appear to have a tremendous potential to aid tasks to reduce vulnerability to wind hazards and to coordinate local and regional planning to prevent/minimize wind-induced losses.

## Benefits of Coordinated Wind Hazards Mitigation Research

Reducing wind hazards risk is a long-term commitment that builds on past experience and advances in our understanding of wind, wind-induced loading on and response of structures, impact of wind-generated debris, and effects of other natural phenomena associated with strong winds (for example surge, hail). Advances in quantifying the physical nature of strong winds, coupled with continuing improvements in engineering methods, will result in significantly increased wind hazard safety, as structures existing in critical wind zones are retrofitted, and new and replacement structures and infrastructure systems are constructed. Research on wind hazards can significantly reduce economic losses resulting from future strong-wind events. Whereas several success stories can be cited, there is a pressing need to continue such research in the future, and at an increased rate.

Because our nation's livelihood is highly dependent on business activity, a future wind event, even one with only a moderate damage potential, can result in significant economic loss. In an extreme case, the recurrence of a hurricane with the magnitude of hurricane Andrew, with landfall passage over a metropolitan area (such as Miami, Florida) would be devastating. Total loss associated with such event is estimated to exceed $30 billion, with a significant portion of this loss attributable to interruptions in business operations. The tragic events of 9/11 in New York City underscore the severity of economic impact of a major disruption in urban infrastructure and interruptions in business activities.

If relevant and timely research coupled with effective technology transfer can reduce the economic loss from a single future strong-wind event by even a very-conservative 10%, the payoff on the investment will be in the billions of dollars.

**Proposal for Establishment of National Wind Hazards Reduction Program (NWHRP)**

In context of arguments put forth in this presentation and findings advanced elsewhere (AAWE Reports[1,7], RAND Report[4], NRC Report[9], NIST Report[10] ), and in view of the current and anticipated future unacceptably high level of wind damage it should be apparent that effective countermeasures are urgently needed and can be developed to stem and reverse these undesirable trends. Evidence has been also presented to support a proposition that an integrated and coordinated long-term effort with well defined, achievable and measurable goals in R&D, education and outreach will be necessary to significantly reduce societal vulnerability to wind hazards with 10 – 20 year time horizon. Such a goal could be accomplished through establishment of the National Wind Hazards Reduction Program (NWHRP). The establishment of such a program was proposed in the past by Jones et al.[11] and others (NRC Report[9], NIST Report[10]).

The concept and implementation of NWHRP program could be built on lessons learned from the 25-year experience with the National Earthquake Hazards Reduction Program (NEHRP). The starting point in this process could be the revised concept of the NEHRP described in the EERI Report[8]. Adaptation of this model for the NWHRP is presented in the AAWE Report[1]. The main components of the program are summarized in Table 1, while the research and outreach tasks are listed in Table 2.

*Table 1. Main Components and Major Areas of Activities of the Proposed NWHRP*

| **Understanding of Wind Hazards** | **Assessment of Impact of Wind Hazards** | **Reduction of Impact Of Wind Hazards** | | **Community Resilience, Education, & Outreach** |
|---|---|---|---|---|
| More Knowledge and Data on Severe Winds | Performance of Buildings, Structures and Critical Infrastructure Using Data Collection, Experimentation & Synthesis | Retrofit Measures for Existing Buildings, Structures & Infrastructure | Cost Effectiveness of Loss Mitigation | Community Resilience to Wind Hazards |
| Better Understanding & Quantification of Wind Loading on Buildings and Structures | Tools for Component and Structure-Level Simulation & Computational Modeling | Innovative Technologies for New Buildings, Structures & Infrastructure | Financial Instruments for Risk Transfer | Cross-Area Outreach & Education |
| Mapping of Wind Hazards | Tools for System-Level/Loss Assessment | Land-Use Measures | Emergency Response & Recovery | Education & Public Outreach |

Implementation of the above concept is based on a sequential progression from Component A through Component D. Significant number of outreach tasks are planned to be activated at appropriate phases of progress in research tasks of all the components of the program, as is illustrated in Table 2.

*Table 2. Breakdown of NWHRP by Research (R) and Outreach (O) Tasks*

| | |
|---|---|
| **A** | **UNDERSTANDING OF WIND HAZARDS** |
| R1 | Enhanced Knowledge on Severe Winds. |
| R2 | Understanding and Quantification of Wind Loading. |
| R3 | Mapping of Wind Hazards. |
| O1 | Enhanced Knowledge on Severe Winds. |
| O2 | Mapping of Wind Hazards. |
| **B** | **ASSESSMENT OF IMPACT OF WIND HAZARDS** |
| R1 | Structural Resistance Using Data Collection. |
| R2 | Tools for Simulation and Modeling. |
| R3 | Tools for System-Level/Wind Loss Assessment. |
| O1 | Structural Resistance Using Data Collection. |
| O2 | Tools for Simulation and Modeling. |
| O3 | Tools for System-Level/Wind Loss Assessment. |
| **C** | **REDUCTION OF IMPACT OF WIND HAZARDS** |
| R1 | Retrofit of Existing Buildings and Structures. |
| R2 | Innovative Strategies for New Buildings and Structures. |
| R3 | Land Use Measures and Construction Practices. |
| R4 | Cost Effectiveness of Wind Loss Mitigation. |
| R5 | Financial Instruments to Transfer Risks. |
| R6 | Technologies for Emergency Response and Recovery. |
| O1 | Codes, Guidelines and Demonstration Projects. |
| O2 | Financial Instruments to Transfer Risks. |
| O3 | Technologies for Emergency Response and Recovery. |
| **D** | **ENHANCE COMMUNITY RESILIENCE, EDUCATION AND PUBLIC OUTREACH** |
| | **COMMUNITY RESILIENCE TO WIND HAZARDS** |
| R | Research Addressing Community Resilience. |
| O | Outreach Addressing Community Resilience. |
| | **EDUCATION AND PUBLIC OUTREACH** |
| O1 | Pre-College (K-12). |
| O2 | College – Undergraduate Program. |
| O3 | College - Graduate Program. |
| O4 | Continuing Education. |
| O5 | Public Awareness & Outreach. |

In formulation of the NWHRP plan attempts were made to develop a dynamic program that would allow for timely use of outcomes of ongoing (in the United States and elsewhere) related research and outreach efforts addressing mitigation of losses due to wind and other natural hazards. A particular attention was given to activities in the area of earthquake engineering, carried out within and beyond the framework of NEHRP.

## Potential Impact of Information Technology

Recent developments in information technology (sensors; data collection, transfer, processing and visualization; experimental and computational simulation; high-end computing; and adaptive networking) have a potential to lead to unprecedented breakthroughs in our efforts to reduce property losses and human suffering due to wind hazards. These advances in information technology (IT) have already significantly influenced activities addressing impacts of natural hazards. Two representative examples of relevance to the NWHRP are discussed below.

The first example is the Network for Earthquake Engineering Simulation (NEES). Significant federal investment has been authorized by Congress for the development of NEES - $82 million over the 2002-2004 period. This funding was allocated for construction/enhancement of engineering laboratories at fifteen universities and development of an advanced networked and grid-enabled experimental, data, and computational infrastructure. This resource makes possible implementation of a concept of "colaboratory" which enables researchers to remotely interact with each other and with their simulation and computational work via "telepresence" tools. Application of these concepts and infrastructure appears to have a great potential for breakthroughs in wind hazards research and outreach. Modest investment to upgrade wind engineering experimental (laboratory/field) and computational infrastructure, coupled with shared use of the NEES networking capabilities would allow for an efficient exploratory application of these technologies in the NWHRP activities.

The second example is utilization of low-cost, small-size (3 ft x 3 ft) networked radars that can be placed on existing cellular towers. These short-range sensors can provide information on low-level winds and other properties of the atmospheric surface layer. They are currently being developed by one of the Engineering Research Centers (supported by NSF) and they are scheduled to be tested in mid 2005, in a networked configuration covering approximately 20 percent of the State of Oklahoma. This technology appears to have potential for application in mapping of wind hazards and in other activities of the NWHRP.

## Concluding Remarks

As discussed in this presentation, significant coordinated federal effort will be required to reverse trend of increasing property losses and human suffering due to wind hazards. The proposed research and outreach plan represents a comprehensive approach to this problem. Implementation of this plan through activities of the proposed NWHRP promises to have a very high level of success in achieving significant reduction in wind hazards impacts within the next decade.

Recent revolutionary developments in information technology (including sensors, data collection, transfer, processing and visualization, experimental and computational simulation, high-end computing and networking infrastructure) have a potential to lead to unprecedented breakthroughs in our efforts to reduce property losses and human suffering due to wind hazards. Sizing the above opportunities will require federal investment to upgrade the existing and develop new research and outreach infrastructure and human resources.

Reduction in material losses and human suffering within the next decade will not be possible without a significant and long-term federal commitment. Moreover, delay in adjustment in federal support in these areas will undoubtedly lead to further (and probably accelerated) deterioration in currently existing national research and outreach infrastructure and in human resources in wind engineering, wind hazards mitigation and in related disciplines.

## References

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**<u>Bibliographical Sketch of Bogusz (Bo) Bienkiewicz</u>**

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